APPLICATIONS OF TOMOGRAPHY TO THE NUCLEAR INDUSTRY

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ABSTRACT

While tomographic methods of reconstructing three-dimensional x-ray images are becoming more common in the medical field, their application to industrial problems has only started. Some of the features that differentiate industrial tomography from medical tomography are

1) x-ray energies may vary from < 10 keV to > 22 MeV,

2) radiation dose to the object is not a constraint,

3) inspection times (within economic constraints) are not as important,

4) the anomalies to be detected offer sharp, high contrast boundaries to the inspection system,

5) high spatial resolution rather than high contrast sensitivity is the primary design goal, and

6) the number of views may be limited by other (mechanical) constraints.

This paper will describe the effort the Los Alamos Scientific Laboratory (LASL) is making to define the design parameters that affect the constraints listed above. A tomographic test bed in which various design features may be evaluated will be described. The computational facilities at LASL, which include a versatile modeling code that can simulate tomographic systems with various types of radiation, geometrics, and detector types, will also be discussed.

Finally some applications of tomography to the nuclear industry will be described. These range from detection, identification, and quantitative mass estimates of fissile material within a container to the detection and measurement of stress corrosion cracks in reactor cooling systems.

Tomographic techniques have recently captured the public interest, particularly in the medical field, although some of the early work was done in desciplines far removed from medicine.[1, 2, 3] The interest now seems to be shifting somewhat back to nonmedical areas and in particular to industrial applications. This paper will describe some of the work being done at the Los Alamos Scientific Laboratory (LASL) and some of our applications of tomography to the nuclear industry.

The basic principles involved are illustrated in Fig. 1. Details of the theory of tomographic reconstruction will not be discussed as they are covered more than adequately in the literature.[4].

First, the constraints imposed upon medical and industrial tomography will be compared.

Medical tomography is primarily interested in one subject, the human body. Granted, different parts of the body are looked at, but compared to the diverse objects inspected in industry, the medical problem is somewhat limited. Within the human body, medical tomography is trying to detect subtle changes in object density or composition using a relatively narrow range of x-ray energies (50 kV to 150 kV). Spatial resolution, while important, is not the primary parameter of interest. In contrast, industrial tomography is interested in reconstructing a cross section from objects that range from a nuclear reactor core (to detect broken or ruptured fuel elements) to the microbeads used as targets in laser fusion research (to measure wall thickness and asymmetries). With these examples of tomographic applications, the x-ray energies needed to penetrate the object will vary from > 25 MeV to 5 keV. With this diversity of objects, the parameter of interest has changed from object density to spatial resolution. Object density is still of interest, but typical features detected in a reconstruction will have air-to-metal interfaces and therefore should be easy to detect. However, the features that are desired to be detected can be small as a crack less than 0.1 mm wide.

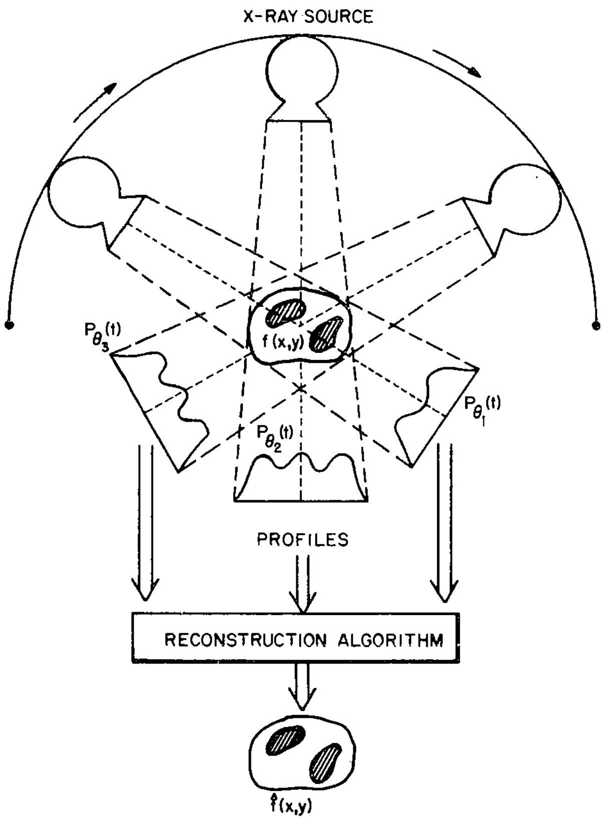

Fig. 1. Typical Tomographic Configuration.

There are other, more obvious differences between medical and industrial tomography. The radiation dose absorbed by the object is unimportant to the industrial user. Time, except as an economic constraint, is relatively unimportant. In many cases, the tomographic equipment may have to go to the object instead of the other way around. And finally, the projection data collected may be less than optimum in terms of number of views, signal-to-noise ratio and spatial resolution for a number of reasons unique to the object being inspected. Because of these differences, medical tomographic equipment and techniques cannot be adapted to industrial use except in a few special cases.

At the Los Alamos Scientific Laboratory, we are developing a modular tomographic system that will enable us to explore the effect of changing parameters (spatial resolution, number of views, etc.) on image quality as well as demonstrate feasibility of performing tomography on particular objects. Figure 2 illustrates the scanner that is being used and Fig. 3, the schematic of the complete system. It must be emphasized that this is a starter system utilizing as much equipment that is on hand as possible. The data acquisition and scanner motion is controlled by a PDP-11/40 minicomputer. While the PDP-11/40 can perform the reconstruction, it does not have a suitable display device for presenting the results to the operator. For this (and other) reasons, the projection data is stored on a nine-track magnetic tape which is then transported to a CDC-7600 computer for reconstruction and display.

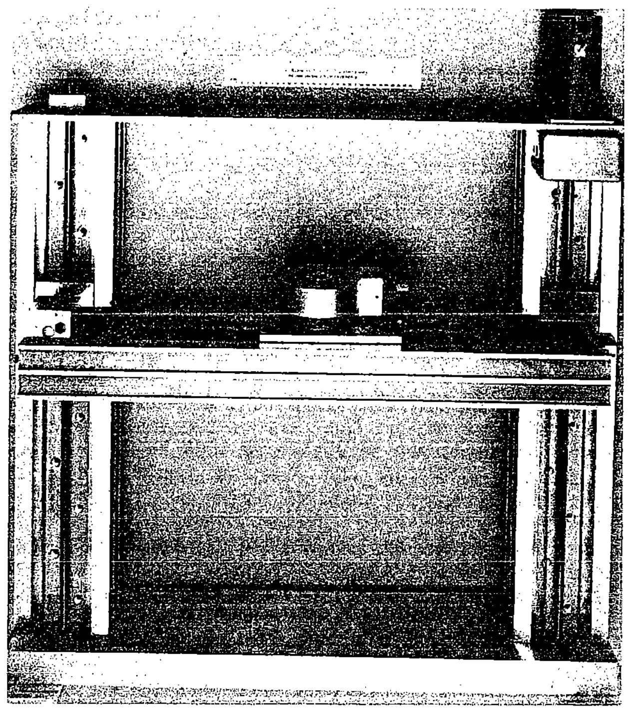

Fig. 2. Tomographic Scanner.

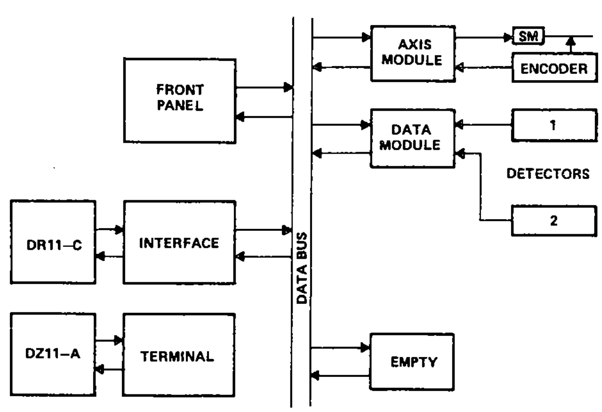

Fig. 3. Tomographic System Schematic.

The first application of tomography conducted by LASL was to detect and locate simulated air bubbles in reactor cooling water piping.[5] Figure 4 illustrates one of the radiographs from which the reconstruction in Fig. 5 was made. In this particular case, the projection data was obtained by scanning 36 radiographs (one every 5 degrees) with a 0.8-mm aperature. The tube wall thickness in this case was 0.35 mm.

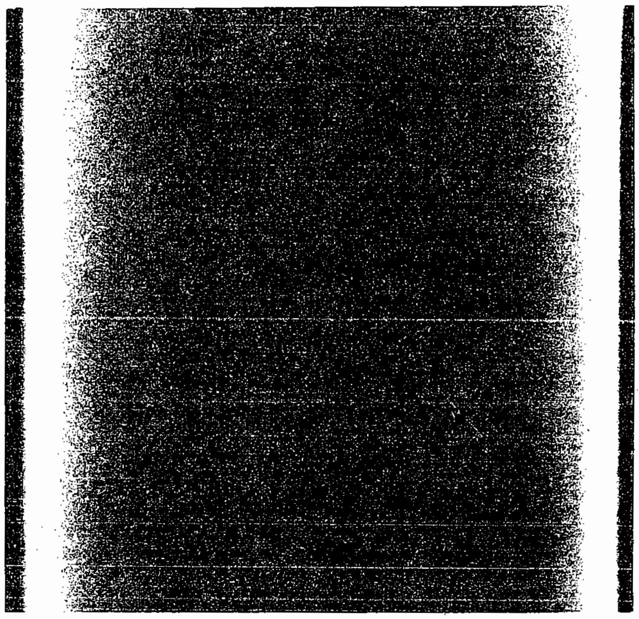

Fig. 4. Radiograph of Simulated Air Bubble

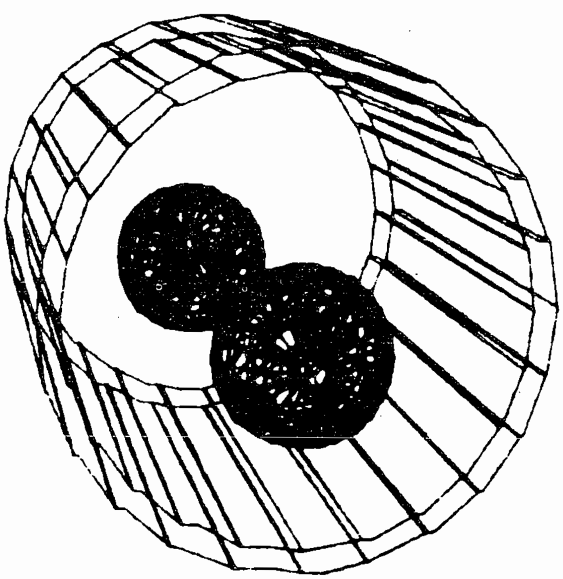

Fig. 5. Line Graphic of 3-D Tomographic Reconstruction

The significance of this simulation is that conventional film techniques, tomographic algorithms, image enhancement algorithms, and line graphic techniques can be combined to produce a useful result.

The next application of tomographic techniques does not involve any data collection. It is a pure simulation to demonstrate the feasibility of performing multi-energy tomography to not only locate objects but also to identify their elemental components.[6]

The object being inspected is a steel can containing pellets of fissile material (U233, U235, PU238). The intent is to generate three tomographic reconstructions of the object using a thermal neutron beam with three fission chambers. One each of the fission chambers would be made from each of the fissile materials. The hope is that the response of each detector will be sufficiently different from the others that an unambiquious determination of the Z number can be made. Figure 6 illustrates the results and Table I tabulates the amplitudes of each material as a function of detector type.

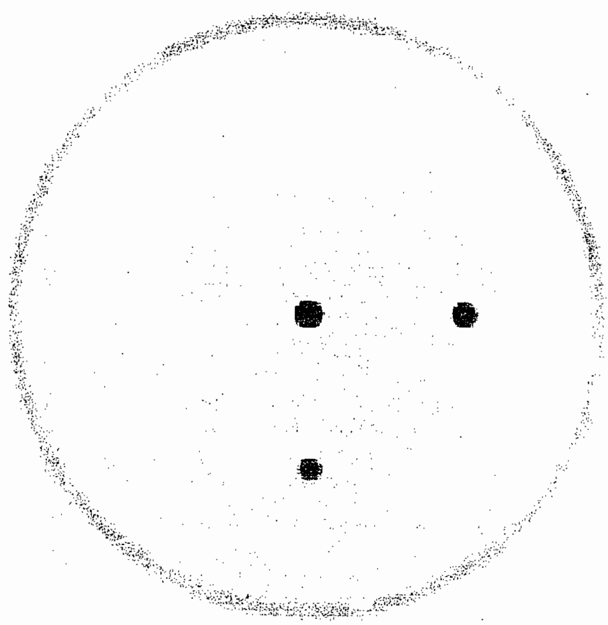

Fig. 6. Tomographic Reconstruction of Fissile Materials.